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ORNL-4446

UC-41 — Health and Safety

HEALTH PHYSICS DIVISION
ANNUAL PROGRESS REPORT
FOR PERIOD ENDING JULY 31, 1969

OAK RIDGE NATIONAL LABORATORY

operated by

UNION CARBIDE CORPORATION

for the

U.S. ATOMIC ENERGY COMMISSION

In aquatic systems with leaves, however, there were considerably smaller and declining cesium concentrations in the water of the nonsterile systems than that of their sterile counterparts as a result of microbial immobilization of cesium by the leaf microflora (Fig. 11.23*e* and *f*). These results indicated that in the water of alternately dry and submerged environments, mineral concentrations may change by one to two orders of magnitude, that new equilibria may be established in times varying from days to months, and that the effect of the microflora in these environments is apparently less than in permanently terrestrial environments.

Various pollutants in water tend to affect the community structure of such waters. Aquatic microcosms of increasing complexity were used to investigate the effect of system structure on mineral kinetics. Community structure was varied by varying compartment combinations. All systems included water with either algae, bottom sediments (materials), snails, or a combination of these compartments. In the presence of snails an additional compartment, detritus, was formed. All systems contained ^{60}Co- and ^{137}Cs-tagged water. Accumulation by algae reached equilibrium within three days, whereas snails kept accumulating radionuclides, particularly ^{60}Co, during the three weeks of incubation. In general, ^{137}Cs reached an equilibrium sooner than ^{60}Co, and simple systems reached equilibria sooner than more complex ones. Water remained the main compartment for ^{60}Co in all combinations. Increase in the number of other compartments simply tended to "dilute" the remaining ^{60}Co over the other compartments. For ^{137}Cs, bottom sediments and detritus were the main compartments. These continued to remove ^{137}Cs from the other compartment throughout most of the incubation time. Thus, structural complexity of the systems affects mineral kinetics, and the effects can be quite different for different elements.

The present overfertilization of waters raises many questions as to the changes in mineral movement in such waters. In order to provide some insight into these changes, transfer of the fallout element cesium and the fertilizer element potassium from eutrophic and oligotrophic water onto various combinations of filamentous algae, snails, and microscopic seston was measured in microcosms. In all combinations less of the added ^{137}Cs than of ^{42}K was removed from the water as a result of greater uptake of potassium than of cesium by algae, snails, and seston. Only detritus, mainly the excrement of snails, retained more cesium than of potassium, indicating greater adsorption and less leaching of cesium than of potassium. In particular, in the oligotrophic series, the retention of both cesium and potassium by algae, snails, and seston was much greater when the compartments were single rather than in combination, probably as a result of competition. A much greater percent of the added ^{137}Cs (up to 40%) and ^{42}K (up to 94%) was removed from the oligotrophic creek water than from the eutrophic river water (10 and 12% respectively). Clearly the river water contained a much larger pool of available cesium and potassium than creek water, and less was taken up by the biota. The mineral availability in river water as compared with creek water was also indicated by the earlier equilibrium reached in river water (within 24 hr), as compared with continued accumulation by algae and snails for two days and longer in creek water. Seston reached a maximum ^{137}Cs and ^{42}K content within 10 hr, probably as a result of the small dimensions of the organisms ($<100\ \mu$). These results demonstrate that in aquatic systems, the smaller the mineral pool and the larger the biomass, the larger a portion of fallout and fertilizer added to an aquatic system will be removed from the water by uptake in the biota; the greater the mineral pool and the smaller the biota, the sooner uptake and elimination will be in equilibrium.

WHITE OAK LAKE STUDIES

S. E. Kolehmainen

The Balances of ^{137}Cs, Stable Cesium, and Potassium in the White Oak Lake Bluegill

The balance of a radioisotope in fish can be simulated with a single-compartment system where the rates of uptake (input) and excretion (output) determine the body burden. In practice the body burden and the excretion can be determined and then the uptake can be calculated. Before making the calculations, one has to know whether the fish is in equilibrium with the radioisotope, because this determines the type of the equation that can be used.

The concentrations of ^{137}Cs, stable cesium, and potassium were analyzed in samples of two to ten bluegill collected one to three times a month from White Oak Lake during the period June 1967 to January 1969. Besides the sampling of fish, samples of different food items of bluegill were also collected. The feeding habits of bluegill were determined on the basis of stomach contents.

The concentration of ^{137}Cs in bluegill increased with size of fish up to 70 g, when a steady state was reached (Table 11.1). Bluegill over 70 g showed a seasonal variation in ^{137}Cs content, with a maximum of 47.4 pc per gram of fresh weight in February and a minimum of 29.0 pc in August (Fig. 11.24). Individual variations of ^{137}Cs in bluegill over 70 g taken on the same day were up to five times. The concentration of dissolved ^{137}Cs in water is also shown in the figure. Dissolved ^{137}Cs was calculated on the basis of the total ^{137}Cs in White Oak Lake water samples analyzed by the Environs Monitoring Section of the Health Physics Division (courtesy W. D. Cottrell) and the proportion of ^{137}Cs in solution in White Oak Lake water, which was 38.5%.[18] No correlation could be seen between the variation of ^{137}Cs in water and in bluegill.

The biological half-life (T_b) of ^{137}Cs increased with the size of bluegill (Table 11.2). There were no significant differences in the long component of the T_b among the fish that received a single feeding of ^{137}Cs and fish from White Oak Lake that had a body burden close to equilibrium (Figs. 11.25 and 11.26). The excretion curve of ^{137}Cs in the White Oak bluegills that were in a steady state with ^{137}Cs did not show any fraction that was excreted by T_{b_1} (Fig. 11.26). However, the calculated proportion of body burden that was excreted by the long component of the T_b in the White Oak Lake bluegill was 2.3%. The standard deviation of the counting was so large that the effect of T_{b_1} on the retention could not be seen (Fig. 11.26).

The concentration of ^{137}Cs in the stomach contents of bluegills was at a maximum in midwinter and a minimum in midsummer. The concentration of ^{137}Cs in bluegills food was calculated on the basis of the percentage of each food item in the stomach samples and the concentration of ^{137}Cs in the food items at that time of the year (Table 11.3). Assimilation of ^{137}Cs from different food items was studied by feeding experiments where the fish were sacrificed after 48 hr, and the body burden, the stomach contents, and the gut contents were counted for ^{137}Cs, or the assimilation was calculated on the basis of the retention curve in the T_b experiment (see Fig. 11.25). The assimilation percentage increased with the size of fish (Table 11.3). Assimilation was low from food containing clay particles (White Oak Lake *Chironomus* larvae and detritus) but was about 70% from organisms not containing clay.

The concentration of stable cesium followed a seasonal cycling similar to that of ^{137}Cs (Fig. 11.27), but the concentration of stable cesium did not increase with the weight of fish (Table 11.1). Potassium concentrations were constant throughout the year (Fig. 11.27) and on the same level in all sizes of bluegill (Table 11.1).

The biological half-life of potassium was determined with ^{42}K by analyzing the daily quantity of ^{42}K that was excreted by fish into water. Potassium had a single-component T_b, 40.1 days, at 15.8°C (Fig. 11.28).

[18] W. T. Lammers, *The Distribution of Cobalt-60, Ruthenium-106, and Cesium-137 Among Suspended and Dissolved Particles in White Oak Lake*, ORGDP report K-1758, 20 pp.

Table 11.1. Concentration of ^{137}Cs in Bluegill of Different Sizes in White Oak Lake

Weight of Fish (g)		Concentration of ^{137}Cs (pc/g)		Number of Fish
Mean	S.D.	Mean	S.D.	
2.1	1.8	10.43	5.59	31
10.5	6.8	13.28	4.32	13
32.0	6.4	21.21	12.69	19
55.1	7.1	30.90	10.52	13
78.0	5.1	39.79	12.69	20
109.6	32.1	40.12	15.21	186

Table 11.2. Combined Results of ^{137}Cs T_b Experiments in Bluegill Calculated for the Temperature 15.8°C

Size of Fish (g)	T_{b_1} (days)	p_1 (%)	T_{b_2} (days)	p_2 (%)
0.5–1.2	6.4	20.6	86.1	79.4
9–10			112.2	
80–120	7.6	36.9	187.1	63.1

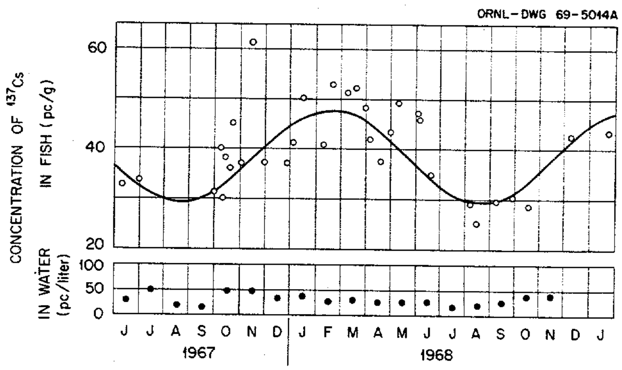

Fig. 11.24. Seasonal Cycling of ^{137}Cs Concentration in Bluegill (70 g) and the Concentration of Dissolved ^{137}Cs in White Oak Lake Water.

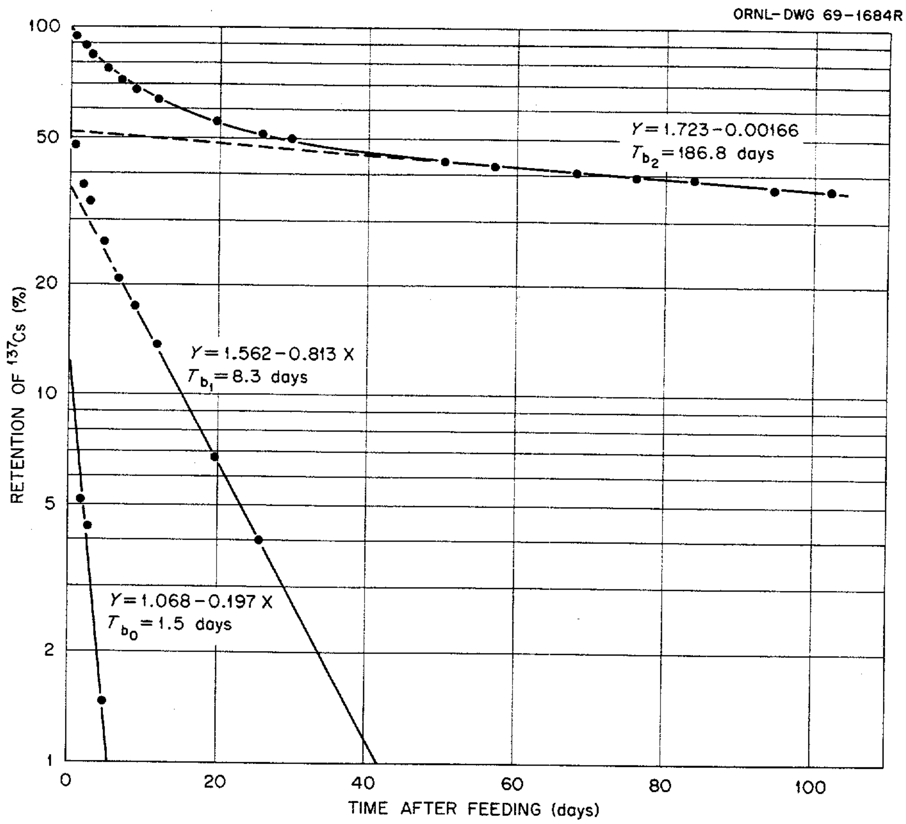

Fig. 11.25. Retention and T_b of ^{137}Cs in a Bluegill (72 g) After a Single Feeding with ^{137}Cs at 15.5°C.

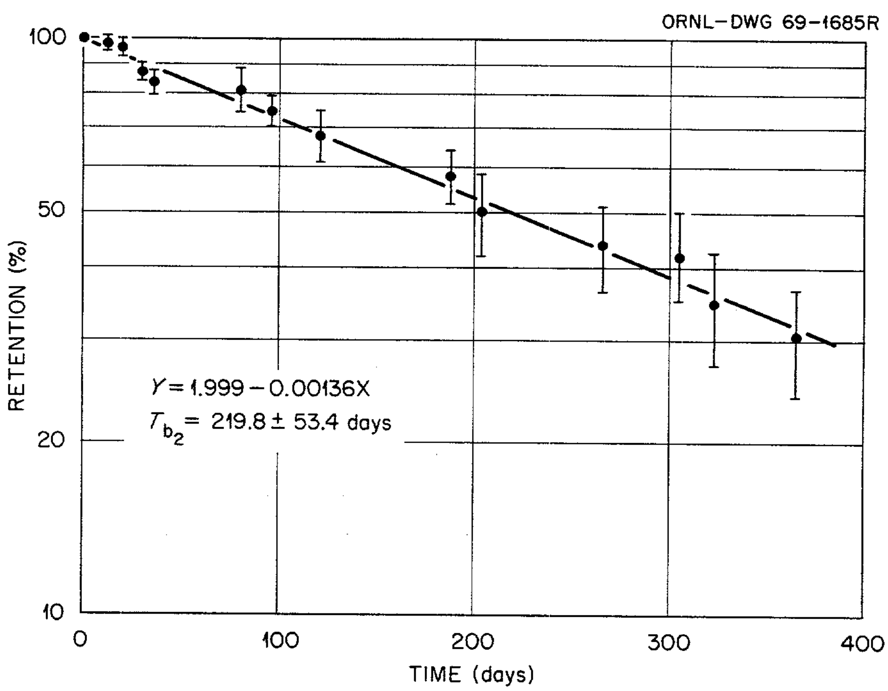

Fig. 11.26. Retention and T_b of ^{137}Cs in the White Oak Lake Bluegill (n = 12) at 14.5°C.

Table 11.3. Percentage Assimilation of ^{137}Cs from Different Types of Food Items in Different Sizes of Bluegill

Food Item	Weight of Bluegill							
	0.5–1.2 g		8–10 g		18–20 g		80–100 g	
	Percent	S.D.	Percent	S.D.	Percent	S.D.	Percent	S.D.
Items similar to those in White Oak Lake								
Chironomus larvae fed on White Oak Lake sediments			7.10	2.08	13.00	2.21	15.98	2.46
Algae							68.72	4.20
Detritus							3.01	0.21
Other types								
Chironomus larvae fed on ^{137}Cs Containing Algae	34.0		68.6	2.2				
^{137}Cs solution in a gelatin capsule							91.3	3.6

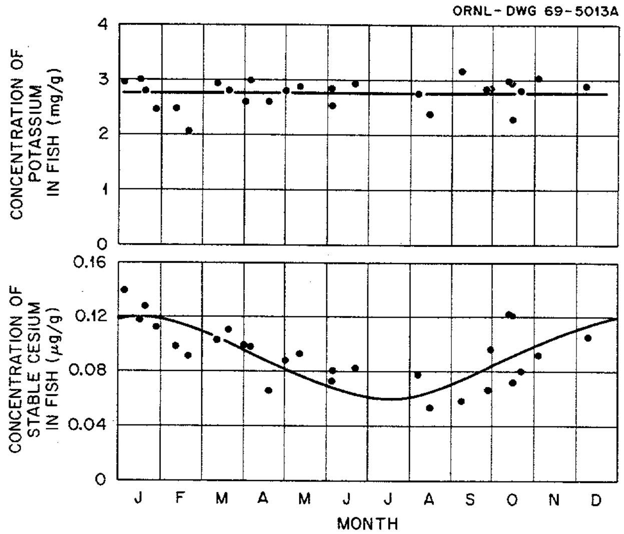

Fig. 11.27. Concentration of Potassium and Stable Cesium in Bluegill over 70 g.

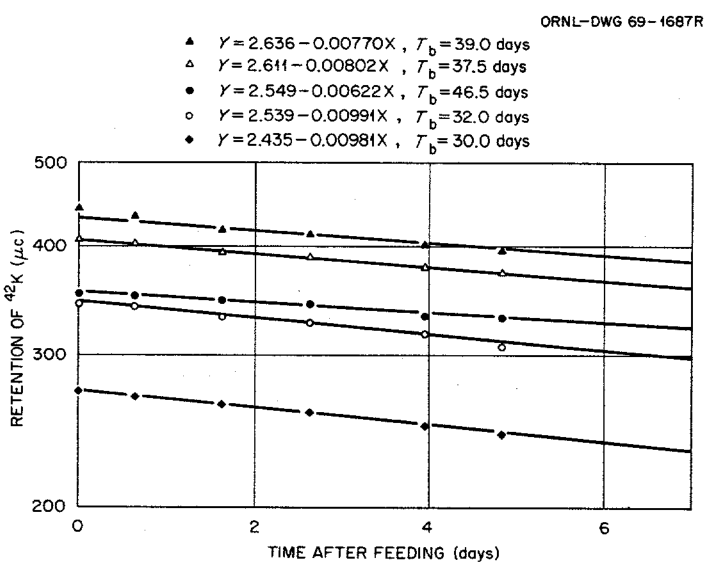

Fig. 11.28. Retention and T_b of Potassium After a Single Feeding with ^{42}K.

Calculation of ^{137}Cs Intake in the White Oak Lake Bluegill

The body burden of ^{137}Cs in bluegill was not in equilibrium because the concentration of ^{137}Cs fluctuated seasonally (Fig. 11.24) and the fish grew yearly. Therefore, calculations of the daily intake of ^{137}Cs were based on a nonequilibrium situation, because all factors, ^{137}Cs, excretion rates of ^{137}Cs, and the weight of fish, were changing daily. The basic equation for the body burden at a nonequilibrium state is:[19]

$$A_t = A_0 e^{-kt} + \frac{I}{k}(1 - e^{-kt}), \tag{1}$$

where

A_t = body burden of the radioisotope at time t,

A_0 = body burden of the radioisotope initially,

k = excretion rate (fraction of body burden excreted per day),

I = assimilated intake of the radioisotope per day.

Since the T_b of ^{137}Cs consisted of two components, the intake was subdivided into two intakes, p_1 and p_2, representing the fractions of each intake that go to the pools of ^{137}Cs in the body excreted by the short component (T_{b_1}) and the long component of the biological half-life (T_{b_2}). By the definition $p_1 + p_2 = 1$, and consequently p_1 and p_2 were the probability values for radioisotope atoms going to either one of the pools.

Equation (1) can now be derived for the intake considering a two-component excretion rate:

$$I = \frac{A_t - (a_1 A_0 e^{-k_1 t} + a_2 A_0 e^{-k_2 t}}{(Ip_1/k_1)(1 - e^{-k_1 t}) + (Ip_2/k_2)(1 - e^{-k_2 t})}, \tag{2}$$

where

a_1 = fraction (pool) of the body burden of the radioisotope excreted by T_{b_1},

a_2 = fraction (pool) of the body burden of the radioisotope excreted by T_{b_2},

k_1 = excretion rate of the radioisotope by T_{b_1},

k_2 = excretion rate of the radioisotope by T_{b_2}.

[19] S. Kolehmainen, E. Häsänen, and J. K. Miettinen, "^{137}Cs in Fish, Plankton and Plants in Finnish Lakes During 1964–65," pp. 913–19 in *Radioecological Concentration Processes* (ed. by B. Åbergand and F. P. Hungate), Pergamon, New York, 1967.

The fraction of the body burden, a_1 and a_2, excreted by T_{b_1} and T_{b_2} can be derived from the equilibrium equation

$$Q_e = \frac{1}{k}, \tag{3}$$

where Q_e is the equilibrium body burden. For a two-component excretion process, Eq. (3) can be written as

$$Q_e a_1 = \frac{Ip_1}{k_1}$$

and (4)

$$Q_e a_2 = \frac{Ip_2}{k_2},$$

and when derived for a_1 and a_2,

$$a_1 = \frac{I}{Q_e} \frac{p_1}{k_1}$$

and (5)

$$a_2 = \frac{I}{Q_e} \frac{p_2}{k_2}.$$

The value of T_{b_1} was 7.6 days, and T_{b_2} equaled 187 days at 15.8°C (bluegill above 70 g). The excretion rate coefficients were

$$k_1 = \frac{0.693}{7.6} = 0.0912$$

and

$$k_2 = \frac{0.693}{187} = 0.00370.$$

The value of p_1 was 36.9% and p_2 was 63.1%; hence, Eq. (5) gives

$$a_1 = \frac{I}{Q_e} \frac{0.369}{0.0912} = \frac{I}{Q_e} 4.05$$

and (6)

$$a_2 = \frac{I}{Q_e} \frac{0.631}{0.00371} = \frac{I}{Q_e} 170.1.$$

Assuming $I = 1$, Eq. (6) can be rewritten as

$$a_1 = \frac{4.05}{Q_e}$$

and (7)

$$a_2 = \frac{170.1}{Q_e} \; ;$$

adding both sides of the equation yields

$$\begin{array}{ll} Q_e \cdot a_1 = & 4.05 \\ Q_e \cdot a_2 = & 170.1 \\ \hline Q_e \quad = & 174.2 \end{array} \tag{8}$$

Now the percentages of a_1 and a_2 can be calculated as

$$a_1 = \frac{4.05}{174.2} 100 = 2.32\%$$

and (9)

$$a_2 = \frac{170.1}{174.2} 100 = 97.7\% \, .$$

The proportion of the body burden excreted at the rate of T_{b_1} (2.3%) was very small in the equilibrium state compared with that excreted by the rate of T_{b_1} after a single meal (36.9%). The percentage of the body burden excreted by T_{b_1} during continuous feeding of ^{137}Cs is shown in Fig. 11.29.

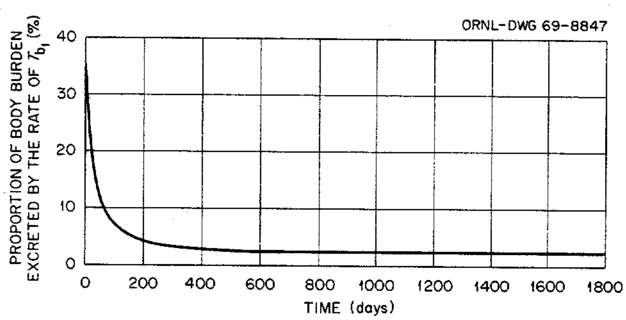

Fig. 11.29. Proportion of Body Burden Excreted by T_{b_1} in Bluegill During Continuous Feeding on ^{137}Cs Contaminated Food. The biological half-lives are T_{b_1} = 7.6 days and T_{b_2} = 187.1 days, with fractional intake of p_1 = 36.9% and p_2 = 63.1%. The proportion of body burden excreted by T_{b_1} in equilibrium, a_1, is 2.3%.

The body burden of ^{137}Cs was not in equilibrium, but the loss term in Eq. (2), $A_0 \, e^{-kt}$, was treated as if A_0 was an equilibrium body burden because there is no practical way to calculate the exact values of a_1 and a_2 for a fluctuating body burden. Since the body burden of ^{137}Cs in White Oak Lake bluegill was close to equilibrium, the error in the values of a_1 and a_2 was small (Fig. 11.29). If the proportions of body burden a_1 and a_2 are used in the loss terms in Eq. (2), separate excretion rate coefficients k_1 and k_2 can be used also. However, since the body burden in the loss term, A_0, is treated as an equilibrium body burden, a weighted excretion rate coefficient, k', can be used as well. The weighted excretion rate coefficient can be calculated either on the basis of proportions of the body burden, a_1 and a_2, excreted by k' and k_2 or on the basis of proportions of the intake, p_1 and p_2, excreted by k_1 and k_2. The weighted excretion coefficient was calculated on the basis of a_1 and a_2 in the following way:

$$Q_e = a_1 Q_e + a_2 Q_e \, . \tag{10}$$

Substituting $I = Q_e k$ in Eq. (10) gives

$$I = a_1 Q_e k_1 + a_2 Q_e k_2 \, , \tag{11}$$

and

$$I = Q(a_1 k_1 + a_2 k_2) \, . \tag{12}$$

The weighted excretion coefficient is

$$k' = a_1 k_1 + a_2 k_2 \, . \tag{13}$$

Since $k = 0.693/T_b$, Eq. (13) gives

$$k' = a_1 \frac{0.693}{T_{b_1}} + a_2 \frac{0.693}{T_{b_2}} , \tag{14}$$

and

$$k' = \frac{0.693(a_1 T_{b_2} + a_2 T_{b_1})}{T_{b_1} T_{b_2}} . \tag{15}$$

The weighted excretion coefficient for the White Oak Lake bluegill was

$$k' = \frac{0.693\,(0.0232 \cdot 187.1 + 0.977 \cdot 7.6)}{7.6 \cdot 187.1} = 0.00573 \, . \tag{16}$$

Since intake (I) and excretion rates (k) are considered constants in Eq. (1), short time units must be chosen.

In the calculation of the ^{137}Cs intake by the White Oak Lake bluegill, the time interval for calculations was taken as one day. Equation (1) was then derived for the intake as

$$I = \frac{A_t - A_0\, e^{-k'}}{(I_{p_1}/k_1)(1 - e^{-k_1}) + (I_{p_2}/k_2)(1 - e^{-k_2})} . \qquad (17)$$

The calculations of intake were based on an average fish in age-group III in January weighing 91.6 g at the beginning of the year and gaining 18.9 g by the end of the year. No correction was made for the losses of ^{137}Cs with the reproductive cells, which were 4.5% in females and <1% in males.

The weight of fish estimated with an empirical fit to a growth curve with maximum growth rate in May, June, and July was

$$M = \arctan\, [0.02(t - 150)] \cdot 7.19 + 100.7 \text{ g}, \qquad (18)$$

where M is the weight of fish in grams, t is the day of the year, and 100.7 is the weight of the fish on the 150th day (May 30). The concentration of ^{137}Cs in bluegill was fitted to a sine function (see Fig. 11.24), and, when multiplied by the weight of fish, it gave a body burden A_t of

$$A_t = \sin\left[\frac{2\pi}{360}(t - 313)\right] 9.2 + 38.2\, M . \qquad (19)$$

The value of A_0 was simply the value of A_t on the previous day or A_{t-1}.

The temperature of water in White Oak Lake was simulated with a sine function:

$$\phi = \sin\left[\frac{2\pi}{360}(t - 105)\right] 10.8 + 15.8°\text{C} , \qquad (20)$$

with a minimum of 5°C in January and a maximum of 26.6°C in July. The relationship between T_b of ^{137}Cs and the temperature was calculated according to Q_{10} law, $Q_{10} = 2$,

$$k_t = k_{15.8}\, e^{0.0693\,\{\sin[(2\pi/360)(5-105)]\ 10.8\}} . \qquad (21)$$

Equations of growth (18), body burden (11), excretion rates k_1, k_2, and k' (21), and daily intake of ^{137}Cs (9) were calculated stepwise with a computer program. Values of weight of fish, concentration of ^{137}Cs, body burden of ^{137}Cs, and weighted excretion rates for a whole year are shown in Fig. 11.30. The intake of ^{137}Cs fluctuated from 0.065 pc per gram of fish in late March to 0.334 pc in August, with an annual mean of 0.256 pc.

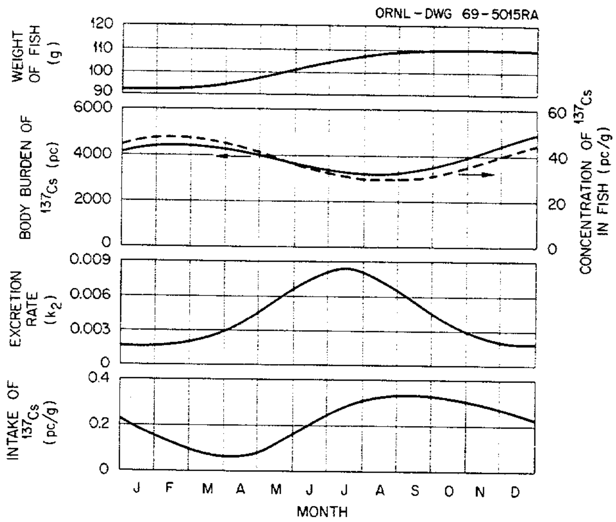

Fig. 11.30. Calculated Values of Weight, Concentration of ^{137}Cs, Body Burden of ^{137}Cs, "Weighted" Excretion Rate (k'), and Daily Intake of ^{137}Cs During a Year for Bluegill in IV Age Group.

The intake of food was calculated with the equation

$$r' = \frac{I}{\Sigma a_i d_i f_i} . \qquad (22)$$

The calculations of $\Sigma a_i d_i f_i$ were made as in the following example. On June 4, 1968, the stomach contents of seven bluegill consisted of 50% chironomid larvae, 20% other insect larvae, 11% plants, and 19% detritus. Thus the quantity of ^{137}Cs assimilated from food was as follows:

Food Item	a_i (%)	d_i (pc/g)	f_i (%)	$a_i d_i f_i$ (pc/g)
Chironomid larvae	16	40	50	3.2
Other insect larvae	16	28	20	0.9
Plants	69	14	11	1.0
Detritus	3	22	19	1.3

The intake I of ^{137}Cs on June 4 was 0.168 pc per gram of fish (Fig. 11.29), and the intake of food was 0.168/6.4 = 0.0263 g per gram of fish, or 2.63% of the body weight.

The feeding rate of bluegill was directly related to water temperature (Fig. 11.29) with a linear regression

$Y = 0.32 + 0.081X$ ($r^2 = 0.665$), where Y is the daily meal (percent of body weight) and X is the temperature (°C). The daily meal was at a minimum (0.84% of body weight) in February and increased slowly during March and April. During May the increase in the feeding rate was rapid, reaching a maximum in June (3.24%), after which there was a gradual decrease until February. Feeding rates of the White Oak Lake bluegill did not decrease as rapidly in the fall of 1967 as in the fall of 1968. This might have been caused by differences in the temperature during these two summers; the summer of 1967 was cool, while the summer of 1968 was hot (Fig. 11.29). Weight of the mean daily meal of bluegill for the whole year was 1.75% of body weight. The ecological growth efficiency in the age-group IV was 6.5% during the period from April to October.

^{137}Cs, Stable Cesium, and Potassium Concentrations and Specific Activities of ^{137}Cs in White Oak Lake Fish

Along with bluegill, samples of six other species of fish were collected during 1967 and 1968 for ^{137}Cs, stable cesium, and potassium analyses. Cesium-137 concentrations in all species followed a seasonal trend similar to that in bluegill, with a maximum in winter and a minimum in summer. The highest concentration of ^{137}Cs was in golden shiner, and the lowest was in redear sunfish (Table 11.4). Concentrations of ^{137}Cs did not show the "trophic level effect,"[20] since the concentrations did not increase with the length of the food chain, but high concentrations of ^{137}Cs occurred as well in primary consumers (goldfish) as in piscivorous (largemouth bass). Low concentrations occurred in primary consumers (goldfish), in omnivorous (redear sunfish), and in piscivorous (warmouth).

Interspecific differences in ^{137}Cs concentrations in fish were caused mostly by the differences in the concentration of ^{137}Cs in food and in the percentage assimilated. The concentration of ^{137}Cs in algae was 35 pc per gram of fresh weight, and assimilation of ^{137}Cs from algae was 69% in bluegill (Table 11.3); this indicates that about 25 pc of ^{137}Cs were assimilated per gram of algae consumed. Assimilation of ^{137}Cs from chironomid larvae was only 16%; and, even though the concentration of ^{137}Cs in chironomids was 96 pc per gram of fresh weight, only 15 pc of ^{137}Cs were assimilated per gram of larvae. The concentration

Table 11.4. Concentration of ^{137}Cs in White Oak Lake Fish

Species	^{137}Cs (pc/g fresh weight)	S.D.	Number of Fish
Gizzard shad	47.03	12.16	15
Golden shiner	62.61	22.05	15
Goldfish	34.53	13.86	10
Redear sunfish	26.85	5.86	40
Bluegill	40.12	15.21	186
Warmouth	36.69	15.75	37
Largemouth bass	52.75	13.14	6

of ^{137}Cs in bluegill and redear fingerlings was 10 pc per gram of fresh weight, and, although predaceous fish assimilate about 70% of their ingested ^{137}Cs, only 7 pc per gram of food must have been assimilated by warmouth. Largemouth bass eat larger fish than warmouth, and, since the concentration of ^{137}Cs in larger fish was higher than in fingerlings, this might explain why largemouth bass had higher concentrations of ^{137}Cs than warmouth.

The concentration of ^{137}Cs in fish of nonturbid and slightly turbid lakes follows the "trophic level effect,"[21] but in White Oak Lake clay particles change the efficiency of ^{137}Cs assimilation so much that ^{137}Cs is not equally available to fish at different trophic levels.

Stable cesium concentrations did not follow the same order as the concentrations of ^{137}Cs (Table 11.5). Goldfish had the highest concentration of stable cesium, while bluegill had the lowest. The concentration of potassium was lowest in goldfish and highest in largemouth bass. Overall, however, the concentrations were rather uniform in all species.

The specific activity of ^{137}Cs varied greatly among the different species. With goldfish, the specific activity was the same as in water, but in the golden shiner it was 2.5 times higher than in water (Table 11.5). These variations indicate there were differences in the availability of ^{137}Cs and stable cesium to different species of fish. This, in turn, leads to the conclusion that ^{137}Cs and stable cesium must have been in different physicochemical states and that some organisms along the food

[20] R. C. Pendleton *et al.* "A Trophic Level Effect on ^{137}Cs Concentration," *Health Phys.* 11, 1503–10 (1965).

[21] S. Kolehmainen, E. Häsänen, and J. K. Miettinen, "^{137}Cs in Fish, Plankton and Plants in Finnish Lakes During 1964–65," pp. 913–19 in *Radioecological Concentration Processes* (ed. by B. Åbergand and F. P. Hungate), Pergamon, New York, 1967.

Table 11.5. Concentrations of ^{137}Cs, Stable Cesium, and Potassium and Specific Activities of ^{137}Cs in White Oak Lake Fish

Species	^{137}Cs (pc/g)		Stable Cesium		Potassium		Specific Activity (pc $^{137}Cs/\mu g$ Cs)	Number of Fish
	Mean	S.D.	Mean	S.D.	Mean	S.D.		
Gizzard shad	42.49	2.84	0.0115	0.0034	3.00	0.14	3710	5
Golden shiner	76.06		0.0145		2.77		5250	4
Goldfish	38.97	8.41	0.0195	0.0085	2.18	0.37	2000	9
Redear	25.29	5.82	0.0090	0.0022	2.81	0.32	2830	29
Bluegill	40.20	15.23	0.0089	0.0023	2.73	0.24	4550	154
Warmouth bass	28.82	11.03	0.0121	0.0031	2.88	0.10	2380	24
Largemouth bass	58.55	6.54	0.0175	0.0023	3.16	0.65	3340	2
Water[a]	58.2	25.6	0.0284	0.0130	1.77	0.07	2050	3

[a]Values are given per liter.

chain of fish were able to concentrate ^{137}Cs more efficiently than stable cesium.

These differences in specific activity of ^{137}Cs among fish species in White Oak Lake make it impossible to apply the specific activity concept in predicting the concentrations of ^{137}Cs in fish, as was done in the Clinch River studies.[22]

Concentration factors of ^{137}Cs varied by a factor of 2 among different fish species (Table 11.6). The concentration factors of stable cesium were lower than those of ^{137}Cs in all species except goldfish, where it was higher. The concentration factors of potassium were fairly uniform.

[22]D. J. Nelson, "Cesium, Cesium-137, and Potassium Concentrations in White Crappie and Other Clinch River Fish," pp. 240–48 in *Symposium on Radioecology* (ed. by D. J. Nelson and F. C. Evans), CONF-670503 (1969).

Table 11.6. Concentration Factors of ^{137}Cs, Stable Cesium, and Potassium in White Oak Lake Fish

Species	^{137}Cs	Stable Cesium	Potassium
Gizzard shad	810	400	1690
Golden shiner	1080	510	1570
Goldfish	530	690	1230
Redear	460	320	1590
Bluegill	710	310	1540
Warmouth bass	630	430	1640
Largemouth bass	910	620	1770